1985

Cognitive performance degradation on sonar operator and torpedo data control unit operator after one night of sleep deprivation.

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THESIS

COGNITIVE PERFORMANCE DEGRADATION ON SONAR OPERATOR AND TORPEDO DATA CONTROL UNIT OPERATOR AFTER ONE NIGHT OF SLEEP DEPRIVATION

by

Mert Kiziltan

September 1985

Thesis Advisor: Charles W. Hutchins

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Cognitive Performance Degradation on Sonar Operator and Torpedo Data Control Unit Operator After One Night of Sleep Deprivation		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis September, 1985
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mert Kiziltan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943-5100		12. REPORT DATE September, 1985
		13. NUMBER OF PAGES 53
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sleep Deprivation, Performance Degradation, Cognitive Skill, Circadian Cycle

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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20. Mental process and decision making) were essential for these jobs (i.e., Torpedo Data Control Unit operator and Sonar operator jobs).

The results showed that subjects were highly sensitive to the sleep loss and their cognitive performance degraded as a function of 36 hours of sleep deprivation and time of sleep deprivation.

Cognitive Performance Degradation on Sonar Operator and Torpedo Data Control Unit Operator After One Night of Sleep Deprivation

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATION RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1985

ABSTRACT

The objective of this study was to examine whether or not relatively short period of sleep deprivation will degrade cognitive skills. Using the Position Analysis Questionnaire (PAQ) two critical submarine jobs were analyzed to reveal the main attributes of the jobs and then the Automated Portable Test System battery (APTS) was used to simulate these attributes. The PAQ analysis showed clearly that the cognitive skills (Estimation, Mental process and decision making) were essential for these jobs (i.e., Torpedo Data Control Unit operator and Sonar operator jobs).

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I. INTRODUCTION

The modern sea battle concept is changing rapidly. The long drawn out wars seem to be a thing of the past. The nature of the war became shorter and shorter in the second half of the twentieth century. The 1967 Arab-Israel war, the 1973 Egypt-Israel war and the 1982 Faulkland Island dispute demonstrated that the fighting was characterized by intense operations requering long hours of physically and mentally exhausting work with a little or no sleep. This occurrance becomes more apparent if we consider submarine operations under combat conditions. submarine operations under combat conditions.

Even in the past, submarines being a surprise and secret weapon had to have long and demanding waiting periods on alert prior to real engagements. Today this waiting period on alert is standing as a vital condition for survival because of the recent developments in Anti-Submarine Warfare (ASW) weapons and ASW capabilities of the twentieth century.

Since today's ASW weapons have been improving in terms of range and lethality, the requirement for a classical, conventional diesel submarine is for its crew to be wide awake even in the pre-war periods. The effect of this situation is a requirement for long hours of physically and mentally exhausting work without sleep.

The silent war of the silent service will be characterized by sustained (continuous) operations. Sustained operations are defined as those operations that are continuous for 24-130 hours without let up in the active engagements. Operations of this type are made possible by;

1. The extensive developments of the combat capabilities of the warships, either in speed or increased sensor capabilities.

2. New operational tactics (e.g.,The use of helicopters and Variable Depth Sonar -VDS)
3. The introduction of the computer to the sea battles

Operations of all types will have to be conducted around the clock. Shift schedules will be modified and probably extended indefinetly in some situations. The increased worklcad will magnify the problems by the intense use of humans in the system.

With intensive use of the human in a system, due to exageneous and endogeneous demands, performance will be affected. There are six major exogeneous demands [Ref. 1].

1. Muscle (Related to the physical work and the muscle groups involved)
2. Perceptual-motor (Due to eye-hand coordination)
3. Cognitive (Related to decision making, vigilance, information processing and communication)
4. Emotional (Related to environmental factors and causes to increased physiological arousal)
5. Temporal (Due to when and how long the task must be performed)

Also five primary endogeneuos variables are (Hegge, 1981)

1. Age (Resource utilization varies directly with age and recovery from fatigue varies inversely)
2. Physical fitness
3. Job skills (The more skilled an individual is at a specific task the longer he can sustain his performance level in a specified level of that task)
4. Health status
5. Psychological fitness (During continuous operations stress will increase)

One of the consequences of the above variables is fatigue. Fatigue will cause a performance degradation in any kind of task. Fatigue may happen primarily as the

result of two factors, physical exertion and sleep deprivation in such a scenario. To help in understanding the effects of sleep deprivation, a relatively short review of the sleep event will be useful.

Since all previous research is consistent in finding strong trends in decreasing of cognitive performances following relatively short periods of sleep loss, the objective of this thesis will be to determine whether or not cognitive skills utilized by submarine operators will be affected by only one night of sleep loss. In this study twelve subjects were deprived of their normal sleep for 36 hours and some defined cognitive skill tests were given to determine the effects of sleep deprivation on cognitive skills found to be important component in a sonar operator and torpedo data control operator tasks.

II. SLEEP AND SOME CHARACTERISTICS

A. CYCLE AND CYCLE EFFECT

One of the complex and urgent problems in dealing with the operations that cause personnel to change their regular day activities is justification and selection of the day duration for a given platform and assignment. Man's development and existence under earth conditions over millions of years has led to complex and stable stereotypes of the physiologic and psychic functions. Man has developed life activity rhythms associated with variation of certain environmental factors which are arbitrarily called " time sensors ". Along with the purely physical phonemena (sunrise, sundown, twillight, nighttime sky) the time sensors of a social nature (breakfast, lunch, productive work, recreational activity and rest) are of tremendous importance.

If there is a difference between metabolic rhythms and time sensors a complex pattern of psychophysiologic adjustments arises, leading to desynchronization phonemena. [Ref. 2]

Another important human cycle is the circadian cycle which is any vital process or bodily function that tends to repeat in approximately 24-hour cycles. It was shown in many different studies that performance tends to degrade if any worker circadian sleep-wake cycle is disturbed. High tempos and workload of operations or dramatic changes in regular day activities need not be present to distrupt the cycle although these will surely do it. Basicly, according to Sborowsky;

" This distruption will happen if a person is awake when his body is 'expecting' sleep or when his body is "expecting" activity, the latter of which will result in a poor quality of sleep that will be evident later in the day."

Every human being has observed an internal fact of body which almost forces him to act in the direction of this force. In other words, the human body operates on an internal clock that regulates certain physiological processes including sleep. These processes are cyclic in occurrance and commonly called the diurnal cycle. [Ref. 3]

Humans as well as animals operate on a cycle that operates 24-hours. [Ref. 4]. Behaviorally we are strongly affected by the diurnal cycle. We eat, sleep, exist based on the internal clock. Regardless of the dark-light cycle we tend to maintain a 24-hour (23 to 25) diurnal rhythm. Physiologically the diurnal cycle affects the body in several ways. For example, task performance peaks between 1200-2100 and its minimum between 0300 and 0600. [Ref. 5]

Some other effects of night are

1. A decrease in function by salivary and other glands of the mouth, nose and throat occurs. This eliminates need to swallow [Ref. 6]
2. Lacrimal secretion decreases during drowsiness and sleep as one become sleepy. [Ref. 7]
3. Gastric and biliary secretion decreases during the sleep cycle. [Ref. 8]
4. The heart rate slows and blood pressure decreases. [Ref. 9]
5. The pupil becomes restricted. [Ref. 10]
6. The body metabolic rate slows down. [Ref. 11]
7. Urinary secretion decreases. [Ref. 12]

These effects occur during the night portion of the diurnal cycle whether one is asleep or awake. Obviously, they will not occur to the full extent if a person is awake, but they do occur and affect human perfomance.

B. SLEEP DEPRIVATION

Although the amount of sleep that humans need varies from individual to individual, recent studies suggest that it will be about 6 to 8 hours per day. Extending wakefullness beyond the time when sleep would normally occur causes the body to function in asynchrony with the diurnal cycle. Reports of the effects of sleep deprivation range from severe performance decrements after a few hours to relatively little decrement after 240 hours. [Ref. 13]

Within a matter of a few hours after entering into sleep deprivation the individual begins to feel sleepy. As deprivation continues, sleepiness increases to a peak between 0300 and 0600. During the late morning hours the individual somehow feels REFRESHED as he enters into afternoon, sleepiness begins to increase again. This cycle continues with the motivation to sleep becoming increasingly stronger each cycle.

In these studies, it was shown that in the early morning hours following the night which sleep deprivation occrred performance will show no dramatic drop while at about 1400 it will show the most dramatic drop and about 2000 it will raise again but not to the extend found under normal sleep conditions. [Ref. 4]

The decline in total sleep duration to 5 to 6 hours per 24 hour period approaches the limit which was found to be the minimum sleep duration which could sustain performance in situations where sleep reduction was gradually and carefully controlled. [Ref. 14]

It has been also shown that the trends of the performance changes due to sleep deprivation irregularities suggest that scheduling of regular sleep periods for personnel may be necessary to maintain performance during extended evaluations.

It is interesting that even the time of the day that deprivation occurs has an effect on performance. [Ref. 15]

C. SLEEP STAGES AND RECOVERY SLEEP AFTER SLEEP DEPRIVATION

There are two possible ways to define sleep and sleep stages. EEG activity analysis which requires expert knowledge to interpret or behavioral signs of sleep. However, sleep is defined by behavioral measures we are faced with the problem of the multiplicity of the measures that do not always agree with one another. Commonly, changes in muscle tone, response to stimuli, and so on may occur in different stages of sleep.

Sleep is conventionally classified into 5 electrically discriminable stages; i.e., stages 1, 2, 3, 4, and 1-REM (Rapid Eye Movement). Stage 1 and stage 1-REM, which is normally associated with dreaming, are commonly thought of as "light sleep". Stages 2, 3, and 4 are considered to be a "deep sleep" period. The differentation of these stages is accomplished by continually recording the electrical activity of the brain with an electroencephalograph (EEG). While a knowledge of the exact electrical nature of the sleep stages is not essential to this thesis, it is necessary to establish that these stages of sleep do indeed accomplish a distinct recuperative process in the body.

A loss or deprivation of stage 4 sleep is characterized by a general sense of ill-feeling. [Ref. 16]. Wilkinson (1968) noted that subjects deprived of stage 4 sleep exhibited marked depressive and hypochondriacal reactions. He mentioned that these hypochondriacal symptoms were aggravated by personality withdrawal, and lessening of the aggressiveness in the individual's normal behavior. Lethargy, exhaustion, and reduced functioning have also been a major effect. A loss of stage 4 sleep for more than 5 days has been likened to a full night's sleep loss.

After several nights of total stage 4 deprivation, almost continuous stimulation is required to prevent a subject from entering stage 4 sleep. It is evident, although not completely apprehended, that some undefined function of this particular stage is virtually essential to the recuperative processes of the body. Another indication of the validity of this conclusion is the "recovery effect". Any reduction in the duration of stage 4 sleep is compansated by a marked increase in stage 4 during subsequent periods. This phenomenon has been noted by all researchers without exception.

The "recovery effect" also holds for stage 1-REM sleep deprivation. Individuals deprived of this dream stage will increasingly attempt to enter it. The effects of REM sleep deprivation appear to differ from stage 4 deprivation indicating a separate recuperative function.

Overall it can be hypothesized that the performance of partial sleep deprived individuals becomes inconsistent and highly unpredictable.

Since it has been shown that deprivation time matters in terms of performance of the individuals, a number of studies were accomplished to examine the effects of selective sleep deprivation. For instance Naitoh [Ref. 17], in his study reported that;

1. A lack of REM or slow wave sleep (SWS)-stage 3 and stage 4- could not be compensated for by other sleep stages.
2. REM and SWS. could be interpreted as providing unique yet undefined functions for the human organism. [Ref. 17]

However he stated that selective sleep deprivation of slow wave sleep or REM stages showed no perfomance decrement as measured by the mathematical addition, the strength of the grip, or pursuit rotor tasks.

It was reported that five nights of REM deprivation resulted in psychlogical disturbances such as anxiety, irritability and difficulty in concentrating.

Johnson [Ref. 18], reported that after two nights of recovery sleep, most subjects would be back to their predeprivation levels but it is still unknown whether similar recuperation would occur if one denied these sleep deprived subjects either REM or slow wave sleep during the first two nights of recovery sleep.

He reported that rebound effect for both REM and slow wave sleep was present for the groups on the first night of uninterrupted sleep, indicating that the selective sleep stage deprivation was effective. Also as with the performance tasks, the return to the predeprivation psychlogical states was the same for all subjects regardless of the type of recovery sleep. It was also noted that the maximum release of growth hormones occur during the first or second hour of sleep, and appears to be correlated with the slow wave sleep.

In their study Naitoh, Englund, Ryman and Hodgen [Ref. 15], hypothesized that the impact of SWS sleep deprivation on recovery sleep would be increased by physical work. They used a 3-hour nap between two 21-hour continuous work episodes. They also experimented with total sleep loss resulting from being continuously awake for 45 hours. They conducted biological tests to examine their working hypothesis. Finally they reported that whether or not the subjects had exercised, physical work did not affect stage 4 duration as long as the subjects had a 3-hour nap. However, they also found that the effect of physical work on stage 4 sleep deprivation depends upon whether the subjects experienced total sleep deprivation combined with exercise. Overall they reported that total sleep deprivation combined with exercise resulted in a greater impact on recovery sleep than sleep loss alone.

D. OTHER ASPECTS OF SLEEP LOSS AND PERFORMANCE

There are many other variables which affect the relationship between sleep loss and performance. For instance, the question of whether the physical strength of the individual has any effect on resisting performance degradation after total or partial sleep loss has always been a matter of interest over the years. There has been considerable speculation in the military about the value of physical fitness in delaying the onset of cognitive degradation caused by sleep loss. But research in this area But research in this area is still in its infancy. A limited study by the Army Research Institute for the Behavioral and Social Sciences (ARI) indicates that being in super physical condition probably will not delay cognitive degradition, at least not during the early stages of sleep loss. [Ref. 4: pp.5-7.]

It is a well-known fact that the quality of sleep is different from person to person, sometimes even from time to time for the same individual. Promotions were taken as performance effectiveness in Navy and "good" sleepers and "poor" sleepers were evaluated on obtaining promotions. The number of promotions obtained by poor sleepers was significantly lower (Only 13 % of the poor sleepers had received promotions in the same period of their careers). In contrast 84% of good sleepers had received two or more promotions during their Navy careers. It was also reported that good sleepers are more effective sailors. It is surprising that since the study used questionnaires to clarify the good and poor sleepers, this classification depended upon individual's self evaluation. But differences in total sleep time would appear to be the least important contributing factor.

Although poor sleepers report subjectively shorter total sleep, over 60% of them showed no significant reduction in sleep when compared to good sleepers in the lab. Also on days off, they reported total sleep time which was not significantly different. The third factor was that the complaint of poor sleep had to be viewed with respect to total psychological state or well-being of the person [Ref. 19]

It was believed that the complaint of poor sleep was significant, regardless of whether this complaint was verified by current EEG sleep measure, in other words poor sleepers have poor coping skills.

There is also a paucity of data on individual susceptibility to sleep loss effects and techniques to measure these individual differences, but there is increased interest in the individual differences in patterns of sleep as illustrated by the studies of natural long and short sleepers. It is clear that there are short sleepers who sleep 6 hours or less, and long sleepers, who sleep more than 9 hours. Whether there are personality and behavioral differences between these groups is still a matter of controversy, but when it is known that reduced sleep will be inevitable, short sleepers may perform better than long sleepers. [Ref. 20]

It was also shown that all types of skills are not affected to the same degree following sleep loss. Continuous sustained performance produces a more rapid deterioration of performance and more disturbing psychological events than would be expected from the sleep deprivation period alone [Ref. 21]

The mental disturbances which their subjects experienced seemed to result from a narrowing of attentional focus onto monotonous, repetitive inputs in combination with a degree of social isolation and sleep deprivation. This raised the

question of whether social contact could ameliorate the performance deterioration and psychological disturbances caused by sustained performance. It had been shown that sustained performance rather than isolation was the main factor in the deterioration which occurred (Mullaney, Kripke, and Fleck, 1981). They stated that had larger number of subjects been studied, the differences between the groups might have reached statistical significance, but social contacts clearly had no profound influence either favorable or unfavorable on the performance of either groups. [Ref. 21: pp. 27-28]

If we consider the confined space interaction with the human capabilities in a submarine operation, we can list a number of side effects which cumulatively affect sleep prospects of a crew. For example, after 265 hours of continuous diving operation, it was found that;

1. Starting about the sixth and seventh day there was a decrease in quality of sleep.
2. Dizziness, irritation of eyes, abdominal tensions and difficulty in breathing were reported frequently and showed no trends in daily ratings.
3. More frequent and severe headaches occurred as mission progressed.
4. 20% of subjects reported some difficulty on concentrating and less over-all efficiency.
5. A deteriorating trend in group morale started the sixth to seventh day.
6. Lowered motivation started the sixth to seventh day.

[Ref. 22]

E. NAP: RESTORATIVE POWER AND SIDE EFFECTS OF THE NAP

Naps are expected to restore the performance which was affected by sleep deprivation. A person somehow feels

REFRESHED after a reasonable period of nap and can work for a while without suffering sleepiness. This fact was expressed by Naitoh, Englund and Ryman basicly as;

> "Among the few means of extending human effectiviness by lessening sleepiness and an accumulation of fatigue during continious work, napping offers the most natural approach."

[Ref. 23: pp.114-117.]

The detrimental effects of sleep loss on performance can only be overcome by sleep of sufficient duration. "Resting in bed" does not help reduce the need for sleep. In theory, two ways are possible to overcome sleep deprivation, either having sleep longer than normal hours and stockpiling excess sleep (if possible at all) or using drugs or sleep inducers. In real life human effectiveness is best extended by providing enough periods for napping during continuous work. [Ref. 23: p.118]

The restorative power of naps differs from individual to individual For habitual nappers an afternoon nap does improve mood and performance within 1.5 to 2 hour period after being awakened from napping.

In field studies, Haslam [Ref. 24], reported recuperative power of small amounts of sleep in maintaining job performance. The side effects of naps, mainly sleep inertia are also of particular importance. Sleep inertia is basicly defined as a drop of major abilities after a napping period. It has been shown that immediately after awakening from a nap, performance may show no improvements and may even be worse than pre-nap levels. This sleep inertia is estimated to last for about 15 minutes but may extent to 2 hours in some cases. Also it may disappear as quickly as 1 to 5 minutes after awakening. [Ref. 25] It was also found that the recovery occurred when a 2-h nap was taken from 1200 to

1400. This particular usefulness of a nap between these hours pinpoints the relation between circadian cycles and naps. [Ref. 26]

After examining the nap event it can be claimed that the recuperative effect of naps depends upon three variables;

1. Hours of prior wakefullness
2. Time of the day when nap is taken
3. Duration

Under the considerations above, it is believed that a reasonable nap scheduling in a continuous work environment may greatly help to reduce performance degradation for the crew which is essential in a real military engagement.

III. SLEEP LOSS AND CONTINUOUS COGNITIVE WORK

The hypothesis that sleep loss will decrease cognitive performance was rigorously supported by many research efforts. In other words, sleep loss and sustained mental work can have dramatic effects on cognitive functions, even during the early stages of sleep deprivation. Many studies also showed that under this continuous cognitive workload, performance systematically declines [Ref. 27], but one should be cautious against difficulties in data transformation, mainly in three major areas. First, performance degradation estimates are highly dependent on the types of tasks subjects are required to perform. Second, intermittent testing, i.e., varying from every hour or two to only once per day does not produce sufficient data to obtain reliable estimates of performance and these data may be confounded by circadian variations. Third, since subjects are usually tested infrequently, they may be able to draw on unused reserves, or capacity not required during interim periods to enhance performance during test periods; thus performance estimates may be spuriously high because of short term high-energy expenditure. Also, if testing is continuous but low in demand, perfomance estimates may still be spuriously high and-hence not generalize well to high-demand sustained operations. [Ref. 27: p. 64]

The study which was conducted by Roland, Heslegrave and Angus [Ref. 27: p.65.], states that it was the first study to systematically examine changes in performance and mood during sleep loss that were dependent upon the current activity of the subject.

One of the reasonable questions to ask is whether the sensitivity of short-duration tasks differs because of the

sleep loss. In serial reaction, logical reasoning, simple iterative subtraction, and complex iterative subtraction tests, it was found that all these cognitive skills have the same sensitivity for both short-duration tasks and relatively long-duration tasks for the same length of sleep loss. [Ref. 27 : pp. 68-71]

Another question is whether performance degradation from a continuous high-demand cognitive environment differs from degradation from a less cognitively demanding environment. Previous studies have revealed that high-demand cognitive environment appears to produce greater decrements in performance. However, this degradation which was measured with respect to a predefined baseline, varied from study to study. For example, most of the studies showed that substantial degradation of performance occurred about 18 hours after the experiments begin for all kinds of tasks. This reduced level of performance was maintained for about 24 hours after which another dramatic drop occurred. But in the study of Heslegrave and Angus [Ref. 27: pp.105-108.], the magnitude of this performance degradation was found to be greater than reported in many studies using similar tasks. Also it was noted that performance and mood showed minimal recovery as a consequence of the circadian rhythm approaching its normal phase during the second and third days. Since a number of studies reported results that were opposed to this result, circadian cycle asyncronization and performance level relations should be investigated carefully.

Also some preliminary evidence concerning tasks that are discrete versus embedded was presented [Ref. 27]. These findings suggest that subjects can maintain performance better on tasks that are separated from their primary function than they can on tasks that are integrated within that primary function.

In many previous studies, it was found that degradation of performance in cognitive tasks was greater than for physical tasks. This result was also confirmed by the study of Haslam. She reported that tasks with a mainly physical content suffered least, and those with a cognitive and vigilance component suffered most compared to control values over the first 4 days of sleep loss. [Ref. 24]

IV. METHOD

A. PARTICIPANTS

A total of 24 subjects were used in this study, 12 of these were the experimental group which experienced 36 hours of sleep loss while the remaining 12 were utilized as a control group. 19 of these subjects were officers in the Turkish Navy, 1 in the Korean Air Force, and 4 of the subjects were wives of the Turkish officers. None of the subjects mentioned any physical or health problems prior to the experiment.

B. DEFINITION OF JOB ATTRIBUTES AND SELECTION OF THE TEST BATTERY

1. Structured Job Analysis

Since there does not exist a limited number of tasks having specific characteristics unique to the submarine environment, and all of the tasks have different working structures, it is difficult to find specific tests that represent the given operational task completely. So the condition for obtaining valid measures from a specific test which is designed to measure some aspect of performance depends upon the selection of the tests. In other words, these tests should reflect critical job attributes. The importance of revealing the major attributes of the job(s) can not be overemphasised.

In this thesis, the Position Analysis Questionnaire (PAQ) was utilized for two critical jobs, namely Torpedo Data Control Unit operator

(TDC) and Sonar operator jobs which are thought to be affected by sleep loss. In order to define job attributes, the PAQ was first proposed by McCormick in 1959. A rating of 8 experts was suggested by McCormick. However, because of the personnel contraints at the Naval Postgraduate School, only 3 submariners were utilized to fill in PAQ questionnaires regarding the sonar operator and TDC operator.

The PAQ was designed to conduct structured job analysis. Structured job analysis procedures provide for the analysis of various jobs in terms of each of a number of "units" of job-related information. Such procedures typically provide for the analysis of any given job in terms of the relevance of each of the "units" in question, the analysis usually being in terms of either applicability to the job or by the use of rating scale indicating the relative extent to which the item does apply. [Ref. 28]

Since there are many different classes of job related information that can be used in structured job analysis procedures, McCormick differentiated between what are referred to as "job-oriented" versus "worker-oriented" elements. Worker-oriented elements tend to characterize the human behaviors that are involved in job activities, such as the nature of the sensory, perceptual, mediation, and physical activities involved in jobs. If there would be any similarities and differences between and among jobs of different professionals, these would be revealed by the use of a job analysis procedure based upon the use of worker-oriented job elements.

Recently, a Navy version of the PAQ was developed consisting of 187 job elements of a worker-oriented nature (Navy edition, Alma F. Harris and Ernest J. McCormick, September 1973).

In general the PAQ was developed to parallel the conventional S-O-R (Stimulus-Organism-Response) model of human activity which is predicated on the concept of a stimulus acting on the organism to cause a probable response. PAQ is basicly divided into six main activities involved in a job;

1. Information output
2. Mental processes
3. Work output
4. Relations with other persons
5. Job context
6. Others.

Various rating scales are provided to evaluate job elements. Most of the rating scales are five point scales ranging from 0 (does not apply) to 5 (the highest scale value) [Ref. 29]

After examination of the PAQ forms which were filled by expert submariners it was found that the main characteristcs of these jobs were (having at least a rating score 2.5 out of 5.0) were;

1. Estimation activities
2. Mental process and decision making
3. Manipulation/coordination
4. Work schedule

All these attributes above (at least the first two) have cognitive elements, and hence if we can employ reliable and well-designed performance tests in terms of stability and construct validity, we can conduct an analysis of whether or not one night of sleep loss will degrade these skills associated with the submarine operation.

Stability is measured by examining the effects of extended practice on means, standard deviations and cross-session reliabities. Means are considered stable if they are level, asymtotic or exhibit constant slope. Standard

deviations are considered stable if homogeneous across sessions. Cross-session reliabities are considered stable after they cease to change over sessions. [Ref. 30]

2. Test Battery -Automated Portable Test System- (APTS)

The next step was to combine the attributes determined above with a well-designed test battery which could simulate the real attributes of the submarine jobs. This requirement was stated in a study by Kennedy and Bittner (1977) as;

> " casual observations over several years of performance testing and a comprehensive reading over 400 'human performance studies' in hyperbaria suggest that there is a need for future studies into standardization of a human performance test battery." [Ref. 31]

They claimed that performance test batteries are often assembled for largely practical reasons on short notice, by persons whose major interest is not performance testing. They also stated that although this distinction is not generally made, it is implicit that performance testing is undertaken for two main purposes; first, to be able to make some statement about the integrity of the organism, and second, to determine whether an environmental factor interacts with an organism's ability to do a particular kind of work. The major advantage of the first approach is that it depends heavily upon the knowledge of the validity of the test. This approach heavily depends upon the following principle of test construction; (1) norms, (2) reliabilities, (3) validities, (4) factors tested, (5) effects of practice, (6) individual differences. If all these principles were satisfactorily fulfilled, it would be possible to employ the test. [Ref. 31:pp. 13-14]

For this reason the Automated Portable Test System (APTS) battery was chosen for the purpose of performance

testing. As we already mentioned, one of the most important aspects of a test battery is whether or not the validity and stability of the included performance tests were proven. In this sense APTS programs were developed following an iterative three stage process; identification, mechanization and evaluation stages.

In the identification stage 30 performance measures were found most suitable statistically for repeated measures applications in an analysis of 140 measures from the PETER[1] (Performance Evaluation Test for Environmental Research) program. The goal during the identification stage is to avoid mechanizing unstable or otherwise unsuitable tests.

In the mechanization stage tests were programmed. In the evaluation stage which is the final and most vital stage, assesment programs were examined for efficiency and construct validity. Thus reliability and construct validity of the PETER program were ultimately assessed. In this sense, APTS provides highly stable tests to simulate real job attributes. Also the experimenter functions have been designed so that they may be accomplished by paraprofessionals. Typically, the overall system has been viewed as very easy to use, reliable and stable in terms of tests applicability to the subjects. [Ref. 32]

After definition of the major attributes of the sonar operator and TDC operator using PAQ results, the following tests were found most appropriate to simulate these attributes;

1. Mathematical Addition Test
2. Sternberg's Short Term Memory Scanning Test
3. Air Combat Maneuver Test
4. Code Substitution Test

[Ref. 33]

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[1]Performance Evaluation Test for Environmental Research, CDR R. S. Kennedy and Alvah C. Bittner, JR.

3. <u>Tests</u>

MATHEMATICAL ADDITION TEST: This test measures the arithmatic facility of the subject. The subject is presented with three (3) two-digit numbers and is instructed to enter the sum of the three numbers. When the test is completed, the subject's test results (i.e., number of questions answered correctly, the number of questions attempted, number of questions presented) are presented on the screen.

This test was chosen, because it represents defined PAQ attributes (i.e., estimation, manipulation/coordination and mental process) successfully.

STENBERG'S SHORT TERM MEMORY SCANNING TEST: This test has been adopted from Stenberg's Short Term Memory Scanning Test. Stenberg assumes that if the selection of a response requires use of information that is in memory, the latency of the response will reveal something about the process by which the information is retrieved. The delay (latency) is interpreted to represent the time taken from stimulus encoding to response processing.

This test was also chosen due to the fact that the cognitive component of this test corresponds well with the major attributes of the two submariner jobs assessed via the PAQ, and responding to a stimulus is an essential part of the mental process and decision making found to be one of the major attributes of the submariners jobs assessed by the PAQ.

CODE SUBSTITUTION TEST: This is a general intelligence test that measures encoding ability and some memory functions. This test simulates the manipulation/ coordination, mental process and decision making attributes which appeared as major attributes in the two jobs via PAQ analysis.

AIR COMBAT MANEUVER TEST: A subject who does well on this test will generally do well on manual control tasks. This test represents manipulation/coordination attribute of the task which again were found to be important dimension of both sonar operator and torpedo data control operator.

The NPRU Mood Scale Questionnaire: This questionnaire consists of a total of 29 questiones. Each of the four response categories is assigned a weight: "not at all," 0; "a little," 1; "quite a bit," 2; "extremely," 3. The sum of the 19 positive items is the P score. The positive items reflect feelings and behavior that generally decrease following sleep loss. The sum of responses to the 10 negative items is the N score. The negative N score usually increases after sleep loss. The P score has been found to be the most sensitive to sleep loss. This scale is provided in Appendix A.

4. Procedure

The performance tests were given to the subjects three (3) times a day, at 0900, 1400, and 2000 following a sleepless night. Also two tests were administrated to get baseline performance values, the first one 24 hours before the sleep deprivation, and the second 48 hours after the third experiment completed and subjects had their normal sleep. These five different experiments were shown as 1, 2, 3, 4, and 5 on the Time Period axis of the performance figures.

In this study 12 subjects were used as the experimental group and 12 subjects were utilized as the control group. In order to overcome matching problems between the control and experiment group, a "YOKED CONTROLS" technique was utilized (Held and Hein, 1963). With this technique, control subjects receive the same stimulation as experimental subjects at exactly the same time as the experimental subjects.

Also a pre-experiment and post-experiment performance test was administered, where pre-experiment was one day prior to the experiment and post-experiment was two days after the experiment. This was done to make sure that subjects returned to their predeprivation sleep/waking states. The tests were given in the same order for all of the subjects. Prior to the experiment, each of the subjects received practice trials on each performance test. In addition they received three practice trials before each test administration during the five test administration times during the experiment.

A regression analysis was conducted. The dependent variable was a dummy variable (if a subject was in the experimental group he received a "1", if he was in the control group he received a "0"). The four independent variables were the scores on the four performance tests.

The experimental group was given the NPRU Mood Questionnaire on two occasions, the first time one day before sleep deprivation and the second right after the experiment was completed. The first questionnaire was used to establish the "Base Line" mood states of the subjects while the second one assessed the effects of sleep loss.

Since both the experimental and base line values were taken from the same subject, a repeated measurements technique was utilized to test whether or not the N scores increased as a result of sleep deprivation and conversely whether the P scores would drop due to sleep deprivation.

A two-way mixed model Analysis of Variance (ANOVA) procedure was used to test the two effects -namely sleep versus nonsleep and time period- on the four performance scores and the extent of interaction between them. In this mixed design, sleep effect was the between subjects factor while test time was the within subjects factor (Winer, 1962).

TABLE I

EXPERIMENTAL MODEL

SOURCE OF VARIATION	df	SS	MS	F
Between subjects	np-1			
A (EXP/CONTROL)	p-1			
Subjects within groups	p(n-1)			
Within subjects	np(q-1)			
B (Treatments)	q-1			
AxB (Interaction)	(p-1)(q-1)			
BxSubjects within groups	p(n-1)(q-1)			

In an experiment of the type represented above, the main effects of the sleep deprivation factor are said to be completely confounded with the differences between groups. On the other hand, the main effect of the time period factor as well as the interaction between factors will be shown to be free of such confounding. Tests on the time factor and interaction will generally be considerably more sensitive than tests on the main effects of sleep loss. Where no confounding with the group factor is present, there are fewer controlled sources of error variance. The smaller the error variance, the more sensitive (powerful) the test. [Ref. 34]

The primary purpose of this design is the control that this kind of design provides over individual differences between experimental units. In the area of the behavioral sciences, differences between such units often are quite large relative to differences in treatment effects which the experimenter is trying to evaluate.

The linear model upon which the analysis will be based has the following form :

$$X(i,j,k) = \mu + a(i) + \Pi k(i) + \beta(j) + a\beta(i,j)$$
$$\beta\Pi(j,k) + \varepsilon k(i,j)$$

The notation $\Pi k(i)$ indicates that the effect of subject k is nested under level a(i).

V. RESULTS

Mathematical Addition Test:

TABLE II

ANOVA-MATHEMATICAL ADDITION TEST

SOURCE OF VARIATION	DF	SS	MS	F
Between subjects	23	8740.31		
Sleep deprivation (SD)	1	10	10	1.792
Subjects between groups	22	122.7	5.58	
Within subjects	48	1931054		
Time period (T)	2	12.21	6.10	4.4516
SDxT	2	27.46	13.73	5.006
TxSubjects within groups	44	60.334	1.371	

For this test, sleep loss has no significant effect. Also, it was found that the time period when the performance tests were given made a difference (P=0.041). It was also observed that sleep deprivation by time period interaction was significant (P=0.017). Since sleep deprivation by time period interaction was significant, a planned comparisons test was conducted on the difference between the experimental and control groups for time period three (1500) which was to be most sensitive to sleep loss. The F value for this comparison was 3.71 (P=0.058).

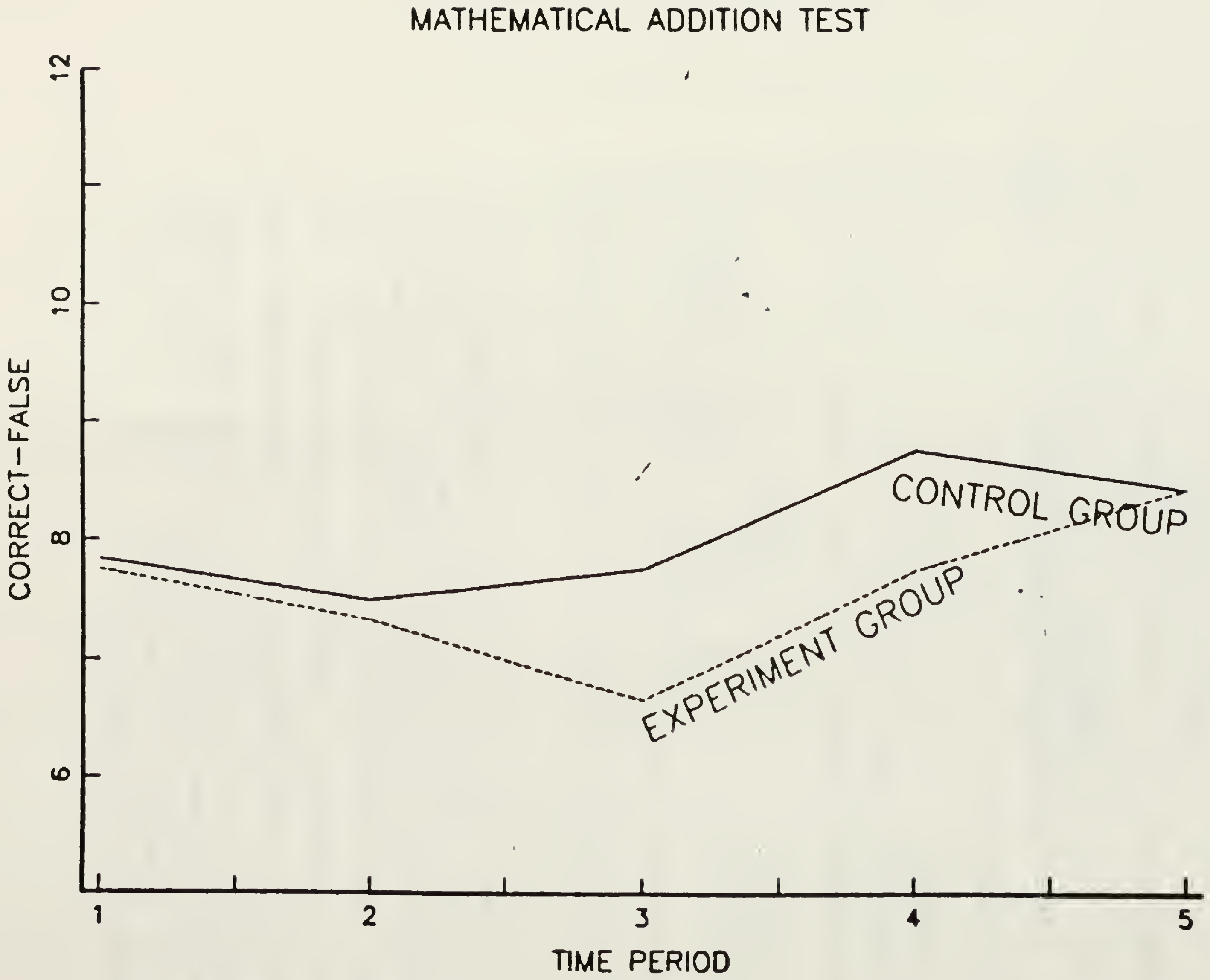

Figure 5.1   Performance On The Mathematical Addition Test.

Stenberg's Short Term Memory Scanning Test:

TABLE III

ANOVA-STENBERGS SHORT TERM MEMORY SCANNING TEST

SOURCE OF VARIATION	DF	SS	MS	F
Between subjects	23	833.241		
Sleep deprivation (SD)	1	100.01	100.01	3.346
Subjects within groups	22	723.2	32.87	
Within subjects	48	484.6		
Time period (T)	2	66.4	33.16	3.88
SDxT	2	42.1	21.05	2.46
TxSubjects within groups	44	376.19	8.55	

For this test sleep deprivation had no effect on performance (P=0.081). However, the time period was significant (P=0.023). No interaction effect was found. The criterion used in this test was correct-false answers.

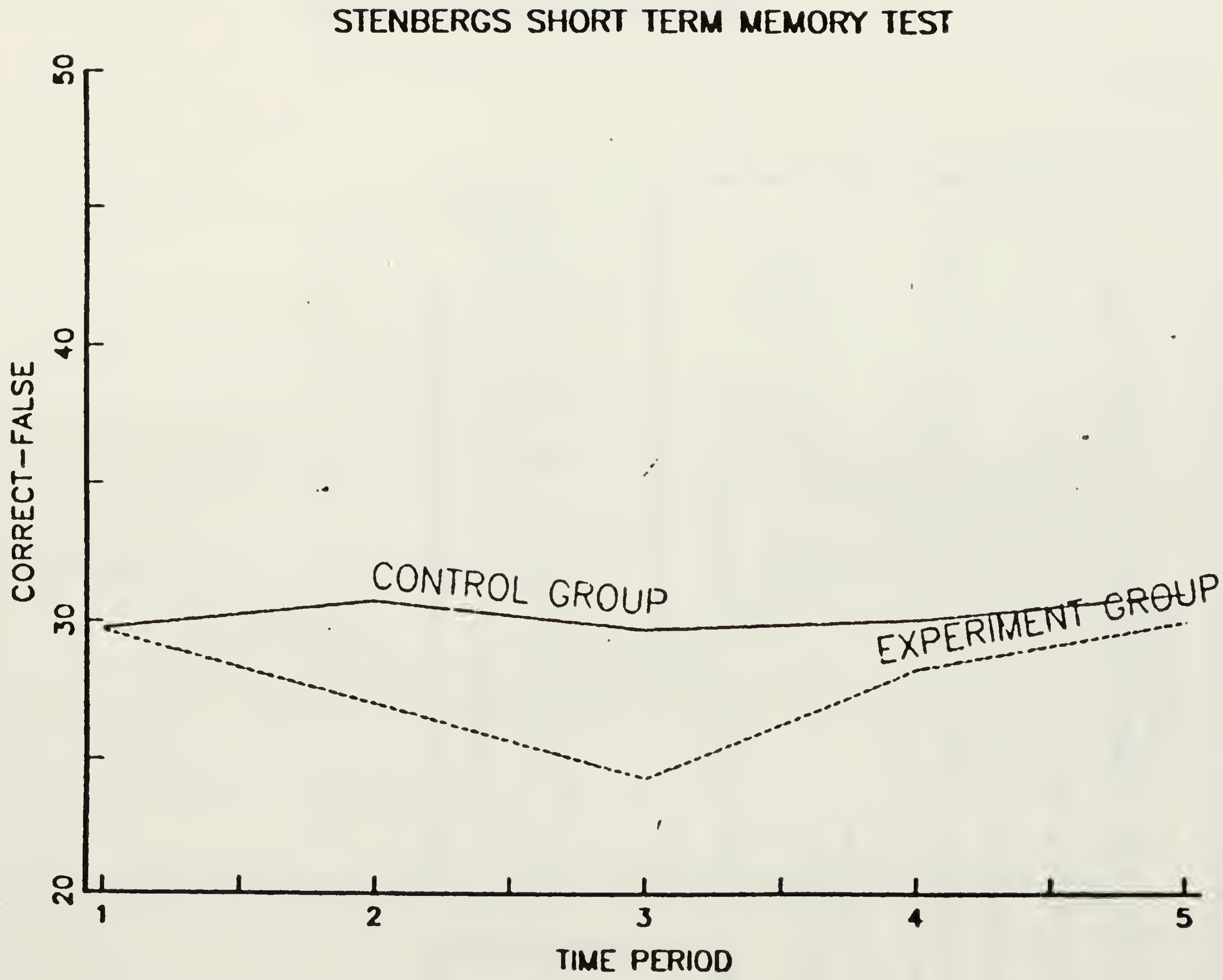

Figure 5.2 Performance On The Stenbergs Memory Test.

Code Substitution Test:

TABLE IV

ANOVA-CODE SUBSTITUTION TEST

SOURCE OF VARIATION	DF	SS	MS	F
Eetween subjects	23	956.5		
Sleep deprivation (SD)	1	410.9	410.9	16.57
Subjects within groups	22	545.6	24.8	
Within subjects	48	3536.7	73.7	
Iime period (T)	2	28.4	14.2	0.178
SDxT 0.504	2	4.19	2.1	0.0263
IxSubjects within groups	44	466,1	10.6	

Control and Experimental group performances were significantly different in this test (P=0.02). But no time or interaction effect were found. The criterion used for analysis in this test was correct-fase answers.

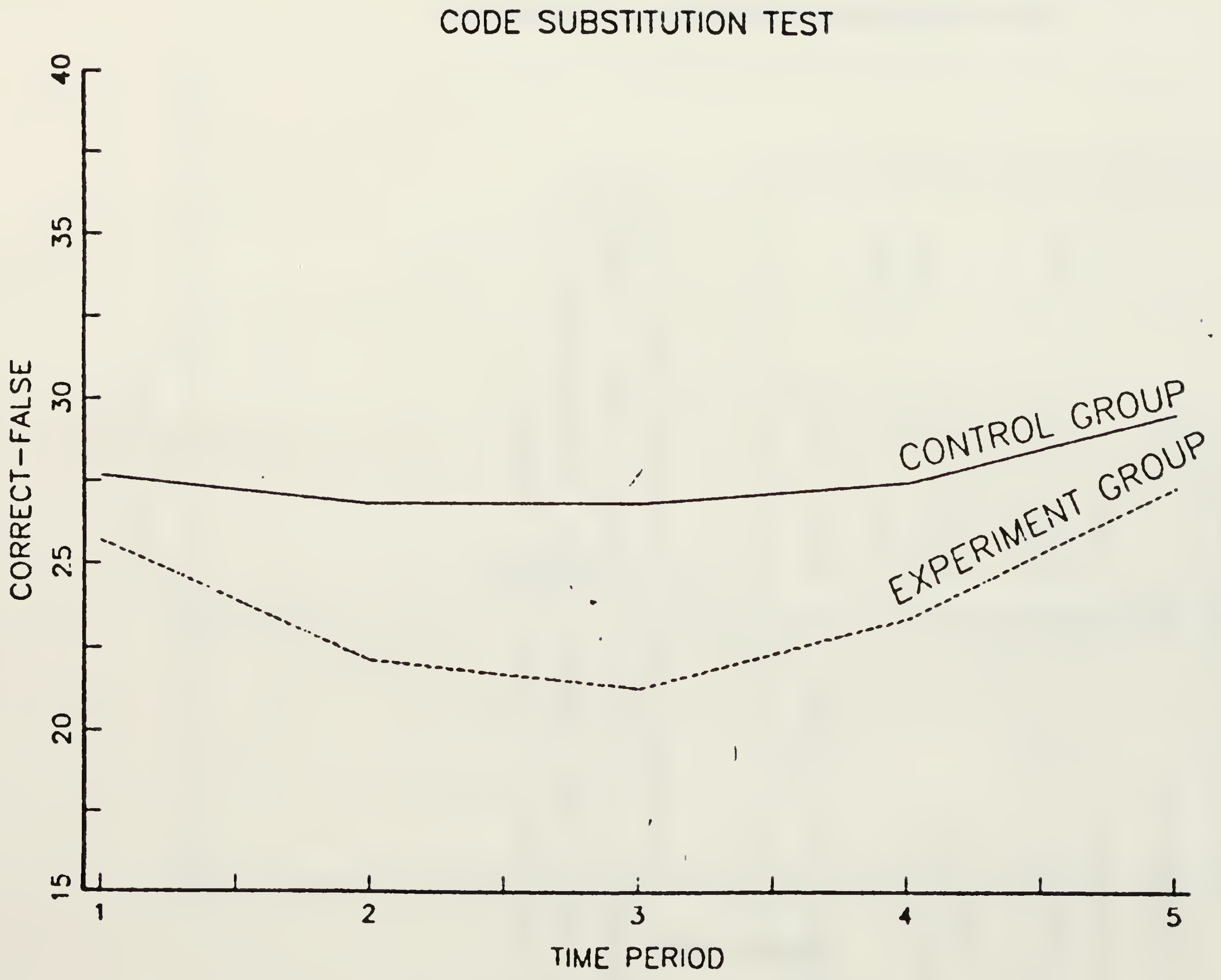

Figure 5.3 Performance On The Code Substitution Test.

Air Combat Maneuvering Test:

TABLE V

ANOVA-AIR COMBAT MANEUVERING TEST

SOURCE OF VARIATION	DF	SS	MS	F
Between subjects	23	34214.7		
Sleep deprivation (SD)	1	4386.7	4366.7	3.22
Subjects between groups	22	29848	1357.7	
Within subjects	48	20906	435.6	
Time period (T)	2	595.8	297.9	2.51
SDxT	2	1638.4	819.2	6.91
TxSubjects within groups	44	5213	118.5	

In this test, the Control and Experimental groups did not perform differently. No time period effect was found while time period and sleep/nonsleep interaction effect was significant. The criterion was total score of the subjects.

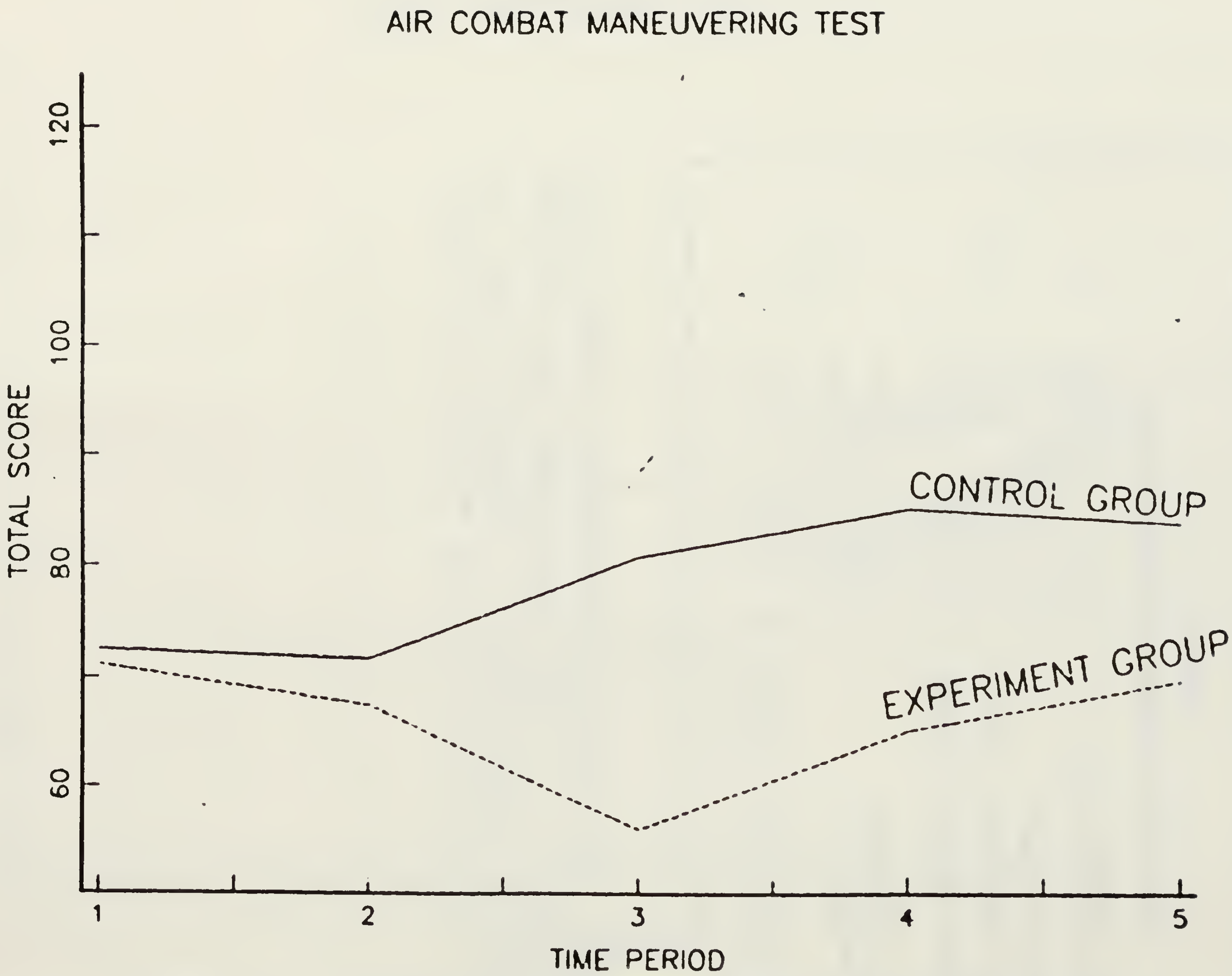

Figure 5.4 Performance On The Air Combat Maneuvering Test.

Regression Analysis: According to regression analysis, the R value for regressing the four performance scores on the sleep loss versus no sleep loss dummy variable was 0.5794. This analysis showed that 58 % of the variation of the difference between experimental and control group was explained by these four test scores. The Code Substitution test had the greatest impact (it was also the only performance score with a significant unique contribution (P=0.0054)).

The NPRU Mood Scale questionnaire revealed that the P scores of the experimental group considerably decreased with respect to baseline mood states indicating that they were affected by this sleep deprivation. Their irritability and discomfort increased while the N scores were increasing. As it is suggested in the NPRU Mood Scale questionnaire, increasing N scores indicated dissatisfaction, mental/ physical fatigue and lowered level of morale. It was also found that the N score was more sensitive to the sleep deprivation than the P scores as it was suggested in the NPRU Mood Scale Questionnaire.

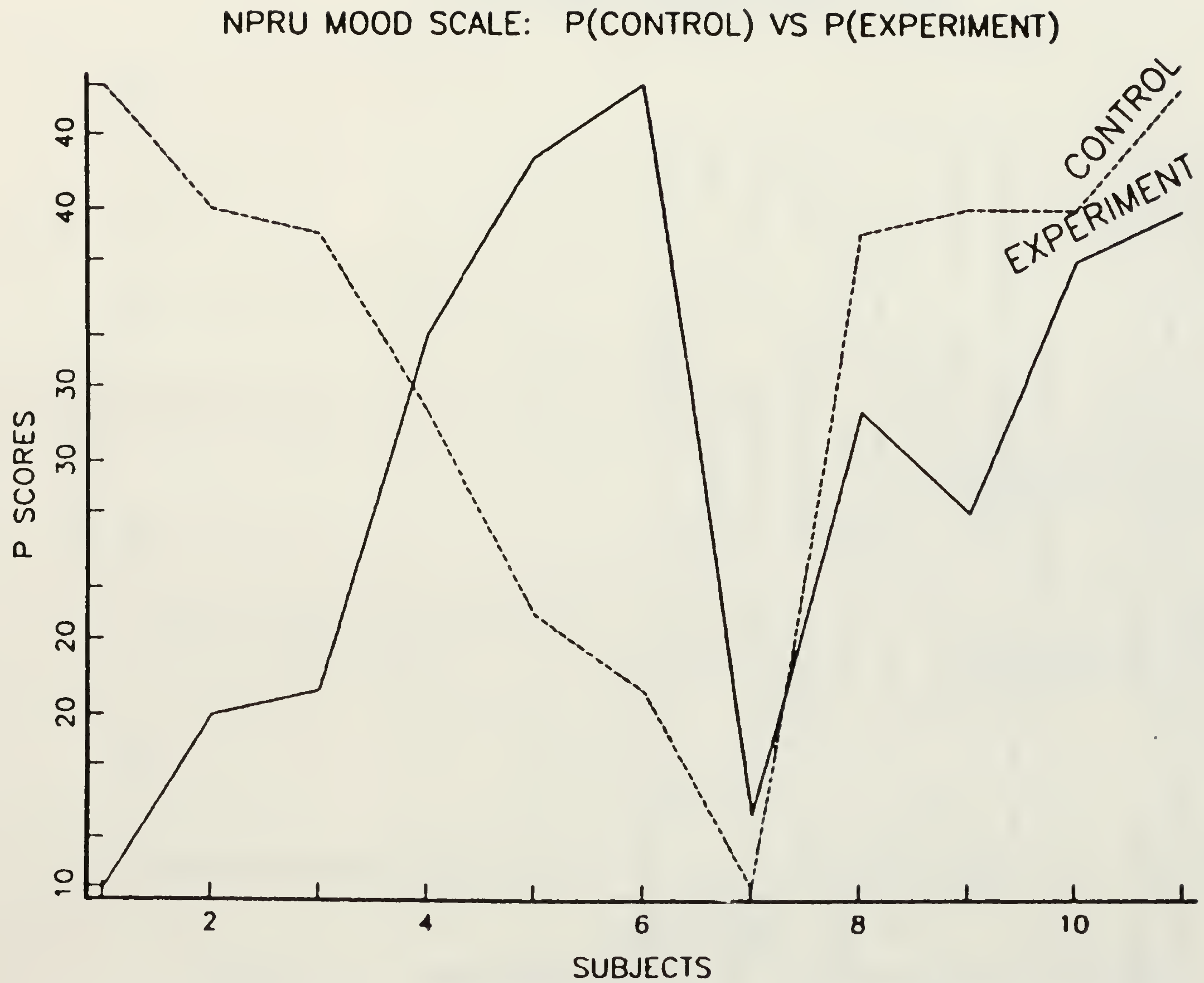

Figure 5.5 NPRU Mood Scale.

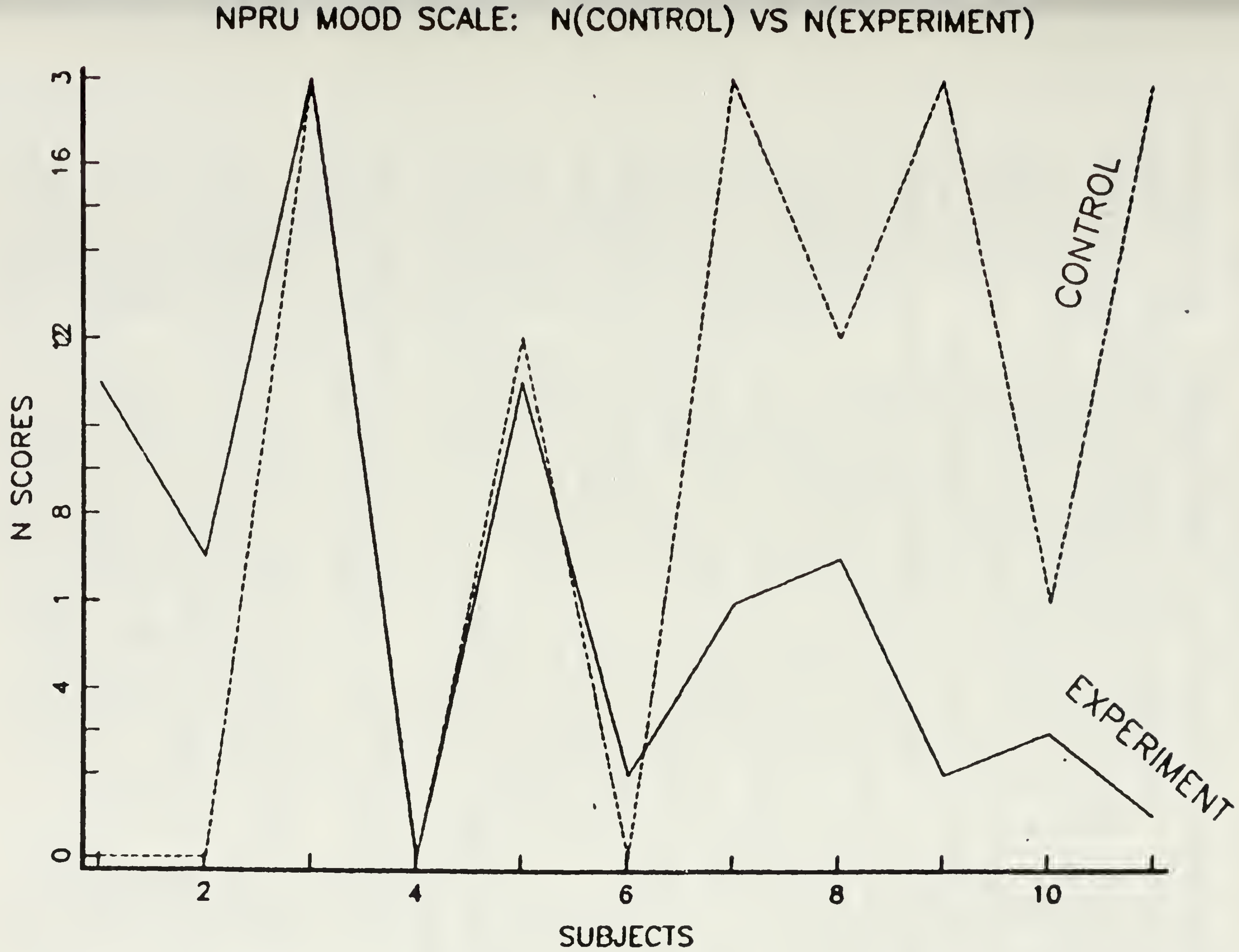

Figure 5.6 NPRU Mood Scale.

VI. DISCUSSION

In our analysis only one test (Code Substitution) showed deterioration of performance due to the effects of sleep loss. Also in Stenberg's Short Term Memory Scanning Test and the Mathematical Addition Test, performance of the subjects varied as a function of time period. In other words, performance changed with respect to when the performance test was given following sleep deprivation. The only interaction effect between sleep deprivation and time period was observed in Mathematical Addition Test and ACM Test.

As determined by the PAQ, the cognitive dimensions of the Sonar Operator job and the TDC Operator job were represented by four tests incorporated in the APTS battery. The findings of this study demonstrated deteriorations of the experimental group performance in one cognitive skill area found to have a special value for submarine environment. Because of the vital importance of these jobs to the submarine in a combat situation, the impact of sleep deprivation on performance can not be ignored. A reasonable sleep/wake scheduling for these two operators is highly recommended in such a scenario.

Some of the main segments of the sonar operator and TDC operator jobs were able to be simulated by these tests as we already discussed. Since the importance of these jobs to the submarine's operational success is obvious, then any potential factor that may cause performance degradation on these jobs should be analyzed carefully.

The findings in Mathematical Addition test and Stenberg's Short Term Memory Scanning test suggest that performance varies in different periods of activity following sleep loss. Since it was found that at about 1400

hours after a sleepless night performance degraded significantly, then both these operators should be relieved of their activities at this period of the day if they have been sleep deprived. These results match with the findings of the previous studies found in Thompson's article [Ref. 4], who also stated that, at about this time of the day circadian cycle effects exacerbate the effects of sleep loss.

Since the Code Substitution test mainly demonstrates a cognitive skill, the performance degradation due to sleep deprivation has a special importance. For example, one of the main characteristics of the sonar operator is to perceive the signal, manipulate it with the available information he has, and after interpretation, to report it. In this sequence, the probable results of any error or incorrect manipulation of the information due to sleep loss need not to be emphasized to realize the necessity of careful sleep scheduling for the sonar operator. Either scheduling a careful sleep/wake regime or increasing the number of qualified sonar operators on board are options which should be given serious consideration by the commanding officer.

The same situation as above was found for the ACM test, also. But this time, as PAQ results suggested, the ACM test is well matched with the segments of the TDC operator job. Hand-eye coordination and decision making aspects of the job were demonstrated very well in this test. Thus the same comments for the sonar operator job are valid for the TDC operator as well.

These above results are powerful enough to predict a performance drop in such a scenario. Whether or not performance was found to be significantly impacted by sleep deprivation, subjects were uncomfortable and their mood state was affected negatively by sleep deprivation.

There are numerous other variables that impact on cognitive performance during sleep deprivation that need to be

investigated. For instance, motivation is the primary factor in performance during sleep deprivation. Since there are many indications that it affects information processing, cognitive complexity of the job under varying levels of stress should be investigated.

In summary, sleep is vital to the individual. Any attempt at self-denial, regardless of how dedicated the individual is, will not result in avoidance of the deleterious impact of sleep loss on critical job skills. The commanding officer must understand the effects of sleep loss, its symtoms and counter-measures.

Both the literature reviewed and the findings of this study suggest that commanding officers should structure the operator's time to include at least some sleep each day. This sleep may not be a traditional, long sleep but may be a short nap sometimes as a part of a careful scheduling effort.

APPENDIX A

NPRU MOOD SCALE QUESTIONNAIRE

NPRU MOOD SCALE
[illegible]

Instructions: For each item, choose one of the four answers that best describes how you [illegible]. Then put an "X" in that box.

NAME						AGE	SEX		
ITEM	NOT AT ALL	A LITTLE	QUITE A BIT	EXTREMELY	ITEM	NOT AT ALL	A LITTLE	QUITE A BIT	EXTREMELY
ACTIVE					GOOD NATURED				
ALERT					GROUCHY				
ANNOYED					HAPPY				
CAREFREE					JITTERY				
CHEERFUL					KIND				
ABLE TO CONCENTRATE					LIVELY				
CONSIDERATE					PLEASANT				
DEFIANT					RELAXED				
DEPENDABLE					SATISFIED				
DROWSY					SLEEPY				
DULL					SLUGGISH				
EFFICIENT					TENSE				
FRIENDLY					ABLE TO THINK CLEARLY				
FULL OF PEP					TIRED				
SCORES	N		P		ABLE TO WORK HARD				

Scoring Instructions: Each of the four possible response categories is assigned a weight: "not at all," 0; "a little," 1; "quite a bit," 2; "extremely," 3. The sum of 19 positive items (active, alert, carefree, cheerful, able to concentrate, considerate, dependable, efficient, friendly, full of pep, good-natured, happy, kind, lively, pleasant, relaxed, satisfied, able to think clearly, able to work hard) is the P score. The positive items reflect feelings and behavior that generally decrease following sleep loss, *i.e.*, feel less active, alert, efficient, *etc.* P scores range from 0 (extremely sleepy) to 57 (extremely active and alert). The sum of the responses to the 10 negative items (annoyed, defiant, drowsy, dull, grouchy, jittery, sleepy, sluggish, tense, tired) is tabulated in the same way to obtain the N score. The negative items usually increase following sleep loss. Negative scores range from 0 (extremely active and alert) to 30 (extremely sleepy). The two scales were included because it was found that certain subjects, such as those in the military, were reluctant to admit negative feelings and behavior while being more willing to admit to change in more positive-type feelings. College students, on the other hand, were more willing to admit to negative feelings such as increased feelings of fatigue, tension, and defiance. The P score has been found to be the most sensitive to sleep loss, and it is recommended that the two scales not be combined.

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Cognitive performance degradation on sonar operator and torpedo data control unit operator after one night of sleep deprivation.